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A Sensor-Driven Fire Model

1. Introduction

Modern building fire sensors are capable of supplying substantially more information to the fire service than just the simple detection of a possible fire. Nelson, in 1984, recognized the importance of tying all the building sensors to a smart fire panel [1]. In this paper, a sensor-driven fire model is described that is designed to achieve a smart fire panel configuration such as envisioned by Nelson. A sensor-driven fire model makes use of signals from a variety of detectors such as smoke, heat, gas, etc. to detect, verify and predict the evolution of a fire in a building. In order to accomplish this task, the fire model must be able to discriminate between fire and non-fire conditions, must be able to recognize detector failure for both fire and non-fire scenarios, and must be able to determine the size, location, and potential hazards associated with a growing fire.

The fire model must be flexible by having the capability to handle fire scenarios in rooms where there may be anywhere from a suite of detectors to no detectors. In the latter case, detectors in adjacent rooms would provide the necessary sensor input to the model. For the suite of detectors, the model must be able to take advantage of the increased amount of information in order to provide earlier and more reliable detection. The model must also be able to accommodate detector failures due to a growing fire and still continue to provide estimations of fire growth and location. Finally, the model must be able to handle a large number of rooms and must complete its calculation cycle in a time interval that is shorter than real time.

2. Sensor-Driven Fire Model

Version 1.1 of the sensor-driven fire model, SDFM, is designed to predict the heat release rate (HRR) of a fire based on signals from either smoke or heat detectors positioned below the ceiling that sample the ceiling jet produced by the fire. The estimated HRR is then used by a variant of the zone model CFAST to predict layer temperature and heights in the fire room and in the adjacent rooms in the building. Based on the predicted layer temperature and height, room conditions such as limited visibility and flashover potential can be deduced. In non-fire situations, the SDFM is designed to look for sensor failure, to discriminate between nuisance signals and fire induced signals, and to monitor the condition of detectors that degrade over time.

The model will spend virtually all its time monitoring the building detectors in the no fire mode. In this mode, the signal received from each detector will be compared with the historic detector record to identify any deviation from normal operation. Detector failure modes will be checked and sensor signals that fall into these modes will result in a trouble (sensor failure) signal being sent to the appropriate monitoring location. Version 1.1 of the sensor-driven fire model has only a simple checking algorithm available that detects sensor failure based on either no signal or a saturated signal from the detector.

When the model receives a detector signal that indicates a HRR increasing with time and has reached a target threshold, the model will try to verify that it is a true fire by assessing the signals received by other available detectors in the area. Such detectors might include CO or CO_2 detectors as well as heat or smoke detectors. If other detectors do not support the fire signal, a trouble signal will be issued and the program will revert to its normal detector polling. If no other detectors are available in the room or if other sensors also support the presence of a fire, a fire alarm will be issued.

The target threshold for the model to start checking for a fire is based on two alternative methods of defining a fire signal. The first method used by the model is to compare the sensor signal with a user prescribed signal. This signal would be one that has been developed by observing the response of the detector to small test fires. The second method would be based on looking at the time history of the detector signal once an estimated HRR based on the detector signal has been reached. If the detector signal indicates a time growing hazard that has reached a particular HRR, a fire alarm will be issued. This second method may allow for earlier detection of fires as well as fewer false alarms since it depends on a time history as well as a signal magnitude.

The determination of a HRR from a detector signal requires knowledge about the characteristics of the detector and its position with respect to the fire. Detector characteristics include the calibration curve for the analog/digital signal generated by the detector as a function of temperature or smoke/gas concentration and the delay time introduced by thermal lag or flow conditions into the sensing element. Once the detector characteristics have been defined, the HRR may be estimated using modeling correlations coupled with a zone fire model. In the following discussion, it will be assumed that only one detector is present in each room. The detector will be located close to the ceiling where it can be considered in the ceiling jet. Presently, version 1.1 of SDFM contains algorithms to estimate HRR from either the excess temperature or the smoke concentration in the ceiling jet [2 3 4].

3. Estimating the extent of fire hazards

Once a HRR has been obtained for one or more of the identified fire sources, this information will be passed to a version of CFAST in order to calculate layer height, temperatures and smoke concentrations in each room of the structure. From this information, hazards such as limited sight, high temperatures, toxic gases and potential for flashover may be identified on a room by room basis for the current fire conditions.

The layer temperatures and smoke concentrations calculated using CFAST are also used to estimate fire spread from the room of origin to adjacent rooms. The signals from sensors in these adjacent rooms are compared with calculated signals based on the estimated layer temperature and smoke concentration predicted by CFAST. If the ceiling jet temperature as estimated from sensor signals is 30% higher than the upper layer temperature predicted by CFAST, it is assumed that a fire has broken out in the adjacent room. If the predicted upper layer temperature exceeds the flashover temperature, 500 °C, it is assumed that a fire has started in that room. In addition, with a known HRR history, projections can be made using CFAST to estimate fire growth and spread. The present version of SDFM does not have this capability.

4. Model Verification

Since the SDFM is designed to operate in a space with a large number of rooms, verification of the algorithms becomes a major problem. One method of verification will be to use the results of multiple room fire experiments and to test the predictions of the SDFM against these experiments. The number of these fire experiments is quite limited, so an additional method of verification is being used. The Virtual Cybernetic Building Testbed at NIST is a computer platform where the building ventilation, heating and cooling, and sensor activities in a multiple room building can be simulated.

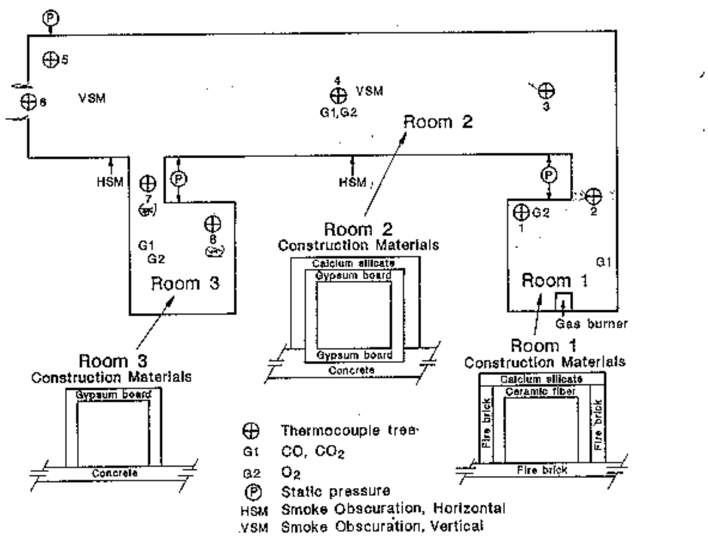
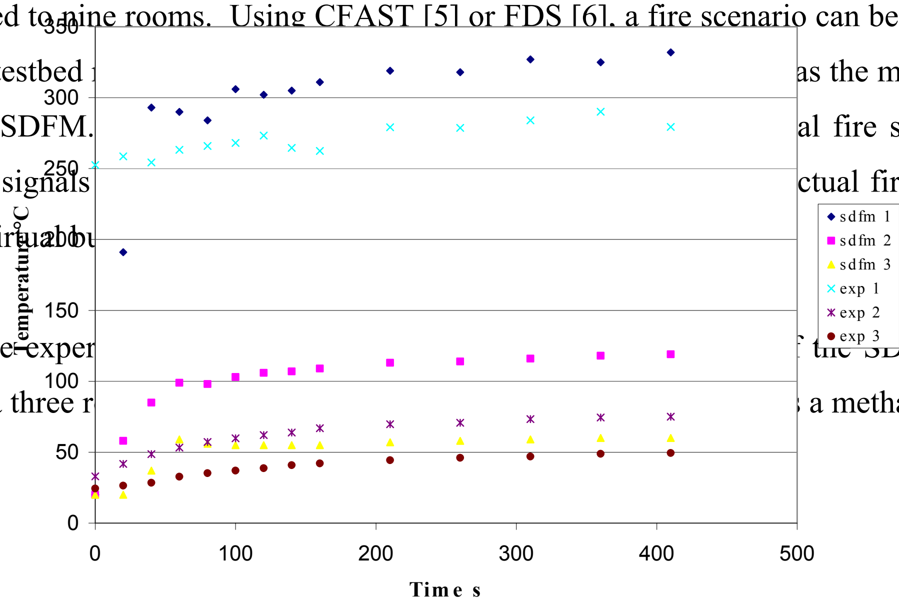


Figure 1 Three-room test plan view.

The present structure modeled in the test-bed contains three rooms and will soon be increased to nine rooms. Using CFAST [5] or FDS [6], a fire scenario can be generated for the testbed … as the model input for the SDFM. … al fire source and receive signals … ctual fire scenario in the virtual bu…



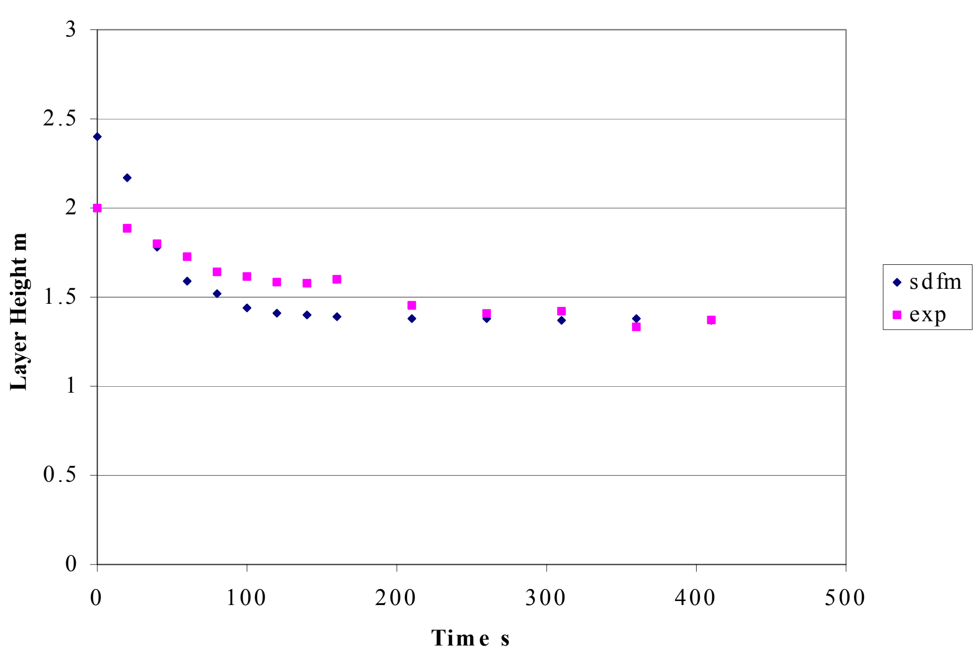
Two fire exper… the SDFM. The first is a three r… a methane burner

[7]. The second experiment is a seven room, two story full scale fire test (Sharon 2) where the major fuel source was wood pallets and flashover was achieved in the burn room [8]. Thermocouple data was available for both experiments and

single thermocouples near the ceiling were used for the SDFM inputs to mimic the response of ceiling mounted heat detectors.

A plan view of the Three-room test is shown in figure 1. The test was modeled as a three-room structure with two short corridors connecting the rooms being modeled as doors. While multiple thermocouple trees and sensors were available in each room, only one thermocouple per room was used to provide a sparse data set for comparison with room conditions. A sparse data set does not provide sufficient information to locate the fire and therefore provides a test of the default positioning algorithm used in the SDFM. The experiment consisted of a methane burner operating at 2.8 kW for the first 330 s of the test. The 2.8 kW fire was increased to103 kW at 340 s into the test. The SDFM detected a fire in the burn room at 350 s into the test. The initial fire of 2.8 kW was below the threshold setting for fire detection in the SDFM.

Figure 2 provides a comparison of the predicted upper layer temperatures of the



SDFM with the calculated upper layer temperatures of the experiment. The plots start from time 0 that is the time that the SDFM detected a fire (350 s into the experiment). The SDFM predictions are higher than the calculated upper layer temperatures of the experiment for the second room but are in good agreement for rooms one and three. The average 95 % confidence interval for this data based on five identical experiments is ± 18 °C, ± 6°C, and ± 4 °C for rooms 1, 2, and 3 respectively.The layer height comparisons for room 2 are given in figure 3. The experimentally measured layer heights are based on observations of the height of the smoke layer in the experiment and are not inferred from temperature measurements. Agreement between the observed layer heights and calculated layer heights are quite good. The average 95% confidence interval for this measurement is ± 0.2 m.

Figure 3 Upper layer height comparison for room 2

The SDFM is designed to provide information concerning the fire threat that fire fighters might encounter in a building. The fire threats presently in the model include: a smoke layer less than 2 m above the floor (limited visibility), a smoke layer above a temperature of 50 °C and layer height below 1.5 m (toxic gas/thermal hazard), and a smoke layer at a temperature higher than 500 °C (flashover). For the three-room experiment, the upper layer temperature did not reach flashover and no flashover warnings were issued. A comparison of the SDFM predictions with the experimental measurements is given in the table below. The SDFM was run with a reporting interval of 20 s.

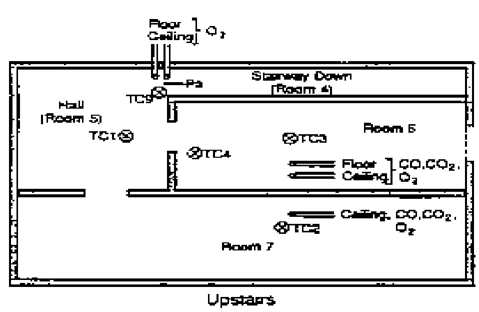
Room	1 EX	1 SD	2 EX	2 SD	3 EX	3 SD
Visibility Limited	na	20 s	20 s	40 s	na	60 s
Toxic Gas - Thermal Hazard; Layer	na	100s	190 s	100 s	na	nr
Toxic Gas - Thermal Hazard; Temperature	0 s	20 s	50 s	100 s	460 s	80 s

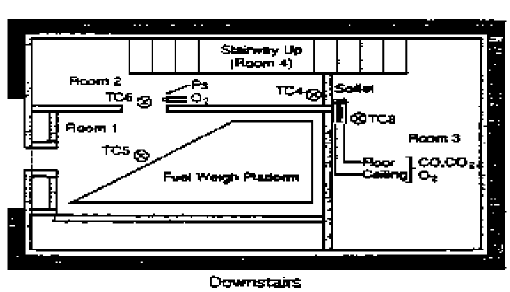
Table 1 Comparison of time of occurrence for three hazard predictions. The symbol "na" stands for not available and "nr" is not reached. 1 EX is the first room experimental results while 1 SD is the first room model prediction.

Experimental layer heights were given for only room 2 in the experiment. Hence, the toxic gas/thermal hazard warning has been separated into two parts, one the smoke layer temperature in excess of 50 °C and the other for a layer height less than 1.5 m. In room 1, the SDFM provided a toxic gas/thermal hazard warning as quickly as it could (based on temperature) and is in good agreement with the experimental measurement.

In room 2, the limited visibility warning was in good agreement with the experimental measurements. The toxic gas/thermal hazard warning was issued roughly 90 s ahead of the criteria being met experimentally. This difference is due to the experimental layer height staying just above the 1.5 m layer height criterion while the calculation predicted a layer height that is just below the 1.5 m criterion (see figure 3).

In room 3, the layer temperature in the experiment remains just below the 50 °C criterion while the calculated value is just above the 50 °C criterion (see figure 2) for an extended time period. The small differences in the experimental and calculated temperatures account for the large difference in the time to issue the warning. Based on the results for rooms 2 and 3, the warning levels used to issue hazard warnings should be set at a lower value than the hazard level so that small differences in the calculations will not delay potential hazard warnings.





To simulate the Sharon 2 test, the seven-room townhouse was divided into eight spaces and thermocouple data was used to provide ceiling jet temperatures in six of

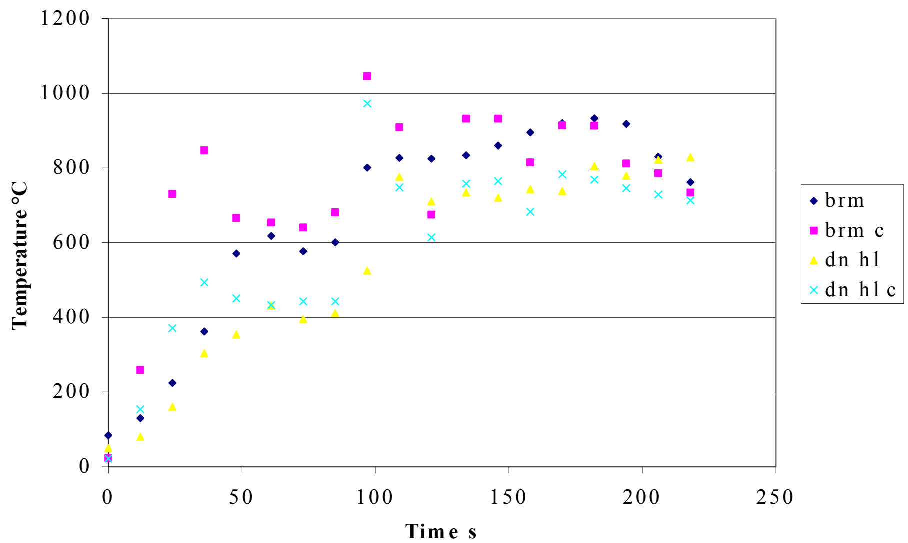


Figure 5 Upper layer temperature comparison for the burn room (brn) and the lower level hallway (dn hl). The "c" indicates the calculation.

the eight spaces. A plan view of the townhouse, showing locations of the instrumentation, is shown in figure 4. In the simulation, room 2 was partitioned into a hallway and a room with the thermocouple tree, TC6, providing the temperatures for the hallway. Thermocouple trees TC1, TC2, and TC3 were used to provide data for the upstairs spaces while TC8 and TC4 were used for the other downstairs spaces. The partitioned room 2 on the first floor and the stairway were modeled spaces with no thermocouple measurements. Only the thermocouple near the ceiling was used for the input data from each tree.

The first 231 seconds of the fire was modeled for the Sharon 2 fire since, in the experiment the wood pallets in the fire room began to fall off the load cell after this time. Figures 5 and 6 provide a comparison of a representative layer temperature as

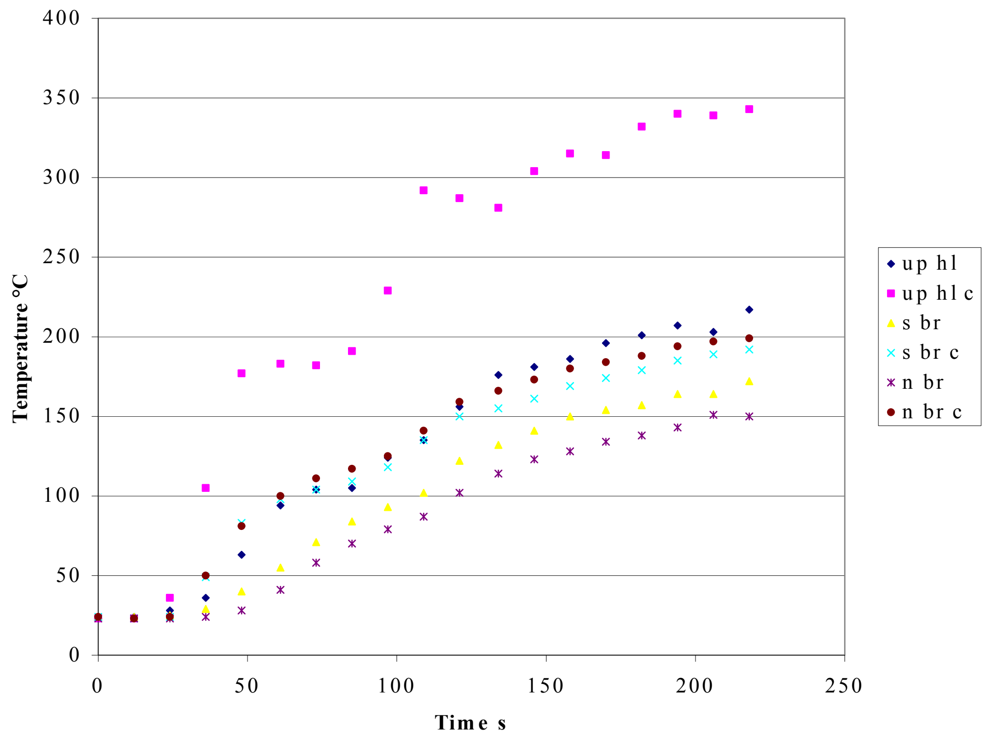


Figure 6 Upper layer temperature comparisons for the upper hallway (up hl), south bedroom (s br), and north bedroom (n br). The "c" indicates the calculation.

measured by the thermocouple trees with the layer temperature calculated by the model for each room. Agreement between the calculations and the measurements is quite good for all rooms although the model tends to overpredict the temperature.

The experimental layer height was determined by estimating the location of the midpoint of the temperature transition between the lower layer temperature and theupper layer temperature. The location of the midpoint above the floor was taken as the upper layer height. The calculated layer heights agree well with the estimated layer heights for most of the comparison interval. Only at the last time intervals for the second floor bedrooms do the calculated upper layer heights drop significantly below the estimated layer heights.

The predicted fire threats correlated well with the estimated occurrence of these threats for the lower level rooms using the data shown in table 2 below. The layer heights were predicted to be lower for the upper level rooms than measured which accounts for most of the differences shown in the table for these rooms. For the bedrooms, the smoke in the room may become well mixed with a two-layer structure beginning to disappear. The cycle time for the calculations and measurements was 12 s, meaning those two or three calculations or measurement times produced several of the time differences.

Room	Burn EX	Burn SD	LL EX	LL SD	UL EX	UL SD	N EX	N SD	S EX	S SD
Visibility Limited	24	12	49	12	88	24	78	49	80	36
Toxic Gas - Thermal Hazard	24	12	49	24	99	36	103	61	94	49
Flashover	48	24	97	97	nr	nr	nr	nr	nr	nr

Table 2 The table presents a comparison of the times in seconds between the experiment (EX) and the SDFM (SD) for the hazard conditions in the burn room (Burn), the lower level (LL) hall, the upper level (UL) hall and the two upper level bedrooms labeled N (north) and S (south). The symbol "nr" indicates that this condition was not reached.

5. Summary

The goal for the SDFM is to provide adequate warning of fire threats within a structure using the building sensors as detectors. For comparisons with two fire experiments, fire warnings were given that were in reasonable agreement with measurements. This agreement was obtained using data from only one sensor per room. Additional sensors in each room would permit the fire source to be more accurately located and as a result better predictive capabilities would be expected. The present results, using only single detectors in each room, provide information that would be of value to fire fighters.

The smoke detector algorithms have not yet been tested experimentally and the model needs to be tested in buildings that contain real detectors and HVAC systems. There are additional algorithms that need to be added or expanded in the model. These algorithms include but are not limited to improving the multiple detector algorithm for a single room, adding lag time algorithms for detectors, expanding the false alarm algorithm in the model, and adding a wall heating algorithm.

Version 1.1 of the SDFM has demonstrated that this type of fire model can give useful results in both simple fire conditions and in fire conditions where flashover occurs.

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[1] Nelson, H. E. Functional Programming/Research Planning for High Technology Federal Office buildings. National Institute of Standards and Technology 1984; NBSIR 84-2828: 28.

[2] Davis, W. D. The Zone Fire Model Jet: A Model for the Prediction of Detector Activation and Gas Temperature in the Presence of a Smoke Layer. National Institute of Standards and Technology 1999; NISTIR 6324: 1-51.

[3] Evans, D. D. Calculating Sprinkler Actuation Time in Compartments. Fire Safety Journal 1985; 9: 147-155.

[4] Davis, W., D. and Reneke, P. Predicting Smoke Concentration in the Ceiling Jet. National Institute of Standards and Technology 2000; NISTIR 6480:1-12.

[5] Peacock, R. D., Forney, G. P., Reneke, P., Portier, R., and Jones, W. W. CFAST, the Consolidated Model of Fire Growth and Smoke Transport. National Institute of Standards and Technology 1993; NISTTN 1299: 1-235.

[6] McGrattan, K. B. and Forney, G. P. Fire Dynamics Simulator – User's Manual. National Institute of Standards and Technology 2000; NISTIR 6469: 1-49.

[7] Peacock, R. D., Davis, S., and Lee, B. T. An Experimental Data Set for the Accuracy Assessment of Room Fire Models. National Institute of Standards and Technology, 1988; NBSIR 88-3752: 1-111.

[8] Levine, R. S. and Nelson, H. E. Full Scale Simulation of a Fatal Fire and Comparison of Results with Two Multiroom Models Volume II – DATA. National Institute of Standards and Technology 1990; NISTIR 90-4268: 1-125.